RESULTS OF THE PRELIMINARY SURVEY ON THE COASTAL DISTRIBUTION OF FISH LARVAE IN ADELIE LAND (SOUTHERN OCEAN) DURING JANUARY-FEBRUARY 1996 *

by

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ABSTRACT. - A first ichthyoplankton spatial distribution survey was carried out in the coastal zone of Adelie Land in Antarctica in January-February 1996. Thirty three stations were investigated in a bay of 25 km^2 surrounded on the southern side by the ice-cliffs of the continent and by the islands of the Pointe Géologie Archipelago on the eastern side. Samples of ichthyoplankton were collected by using a bongo net towed from the surface to near the bottom for depths less than 200 meters. Five species were caught but *Pleuragramma antarcticum* was dominant comprising 99% of the larval fish captured. A dense swarm of at least 17 individuals.m^{-3} was detected in the study area but densities were on average lower than 1 individual.m^{-3}. Distribution of the larvae was explained by hydrological features and we believe that a major factor is the development of coastal gyres linked to the topography.

RÉSUMÉ. - Résultats de la campagne préliminaire sur la distribution des larves de poissons dans le secteur côtier de Terre Adélie (Océan Austral) en janvier-février 1996.

Une campagne préliminaire sur la distribution spatiale de l'ichtyoplancton dans la zone côtière de Terre Adélie en Antarctique a été réalisée en janvier-février 1996. Le réseau d'échantillonnage comprenait 33 stations et couvrait une baie de 25 km^2 limitée au sud par les falaises de glace du continent et à l'est par l'archipel de Pointe Géologie. L'ichtyoplancton a été échantillonné par un double collecteur bongo de la surface au fond pour les profondeurs inférieures à 200 m. Cinq espèces ont été capturées mais les larves de *Pleuragramma antarcticum* étaient dominantes à plus de 99%, se localisant sous la forme d'un essaim dense d'environ 17 individus.m^{-3} alors que les densités larvaires étaient de 1 individu.m^{-3} en moyenne. La distribution de ces larves est expliquée par l'hydrologie du secteur et probablement par la présence de gyres côtiers associés à la topographie.

Key-words. - Nototheniidae, *Pleuragramma antarcticum*, Bathydraconidae, PSE, Antarctic Ocean, Adelie Land, Ichthyoplankton, Spatial distribution, Variogram.

From January to the beginning of February 1996, a joint French-Italian ichthyological research program was held in the coastal zone of Adelie Land at 140°E, 66°40'S. It

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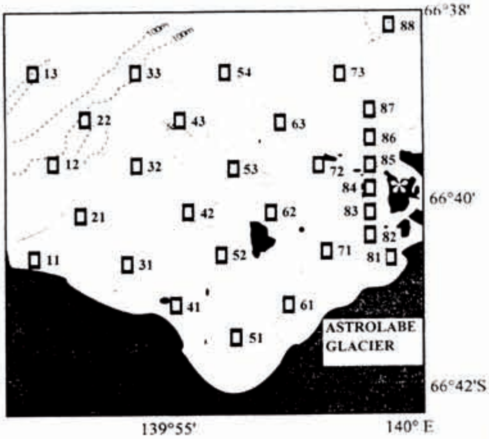


Fig. 1. - Localisation of the sampling network.

was the second main survey in this sector after the research work undertaken from 1960 to 1962 by Hureau (1970). The studies were carried out in the Pierre Lejay Bay of 25 km^2, located in the Dumont d'Urville Sea close to the French coastal station (Fig. 1).

The Bay is surrounded on the southern side by the ice-cliffs of the continent and the Astrolabe Glacier. The eastern boundary is formed by the numerous islands and islets of the Pointe Géologie Archipelago. There, depths vary from 10 to 70 m and the area is usually covered by small icebergs and numerous fragments of glacier ice from the Astrolabe Glacier. The western part is characterized by the presence of an inner-shelf depression with a northeast to southwest axis and maximum depth of about 550 m. This area was usually free of icebergs. The northern part of the Bay is open to the continental shelf with average depths varying from 100 to 400 m. This area is marked by the path of the largest icebergs coming from the east. An important feature is the presence, on the east of the Archipelago, of a deep inner-shelf depression of more than 1000 m north-westward from the Astrolabe Glacier.

During this program, nets, trammel net, traps and long-lines were used to collect juvenile and adult fish for taxonomy, community analysis and phylogeny (Hureau *et al.*, 1996). In 1970, Hureau assumed that the young stages of fish may have a pelagic phase and return to the spawning zone when they reach sexual maturity. Norman (1938) stated that most notothenioids have pelagic larval stages and change their biotope at metamorphosis to become demersal. Hureau (1970) proposed that further studies should take place to investigate the early life history pelagic phase of Antarctic fish species. Thirty years later, many ichthyoplankton surveys have taken place around subantarctic islands, the Antarctic Peninsula and Weddell Sea (see Loeb *et al.*, 1993 for a review) but no results were available from the Adélie Coast sector.

One aim of the program was to carry out a fine-scale ichthyoplankton and oceanographic study to investigate, in a coastal zone, the larval spatial patterns of the locally dominant Antarctic fish. Five species were caught: *Pleuragramma antarcticum* Boulenger, 1902, *Trematomus newnesi* Boulenger, 1902, *Trematomus lepidorhinus* Pappenheim, 1911, *Trematomus scotti* Boulenger, 1907 and *Racovitzia glacialis* Dollo, 1900. *P. antarcticum* was used to study larval distribution patterns and the abiotic factors that may control them because of this species relative abundance.

MATERIAL AND METHODS

Field work

Thirty three stations were investigated (Fig. 1). At each station, temperature and salinity vertical profiles were measured by using a Seabird 19 CTD. Surface chlorophyll and mesoplankton WP2 (200 µm mesh) vertical hauls were also undertaken to obtain information about the biotic factors that may influenced fish larvae (Razouls and Koubbi, unpubl. data). Samples of ichthyoplankton were collected by using a light framed bongo net (500 µm mesh). The sampling gear was towed from the surface to near the bottom for depths less than 200 m and stopped at 200 m in greater depths. An acoustic system was used to precisely locate the depth of the net in the water column.

Larvae were preserved in a 5% formaldehyde solution (w:w) buffered with sodium tetraborate. All larvae were counted and identified using the key of Kellermann (1990). At each station, the standard length of individual larvae was measured except for *P. antarcticum* for which subsamples (of about 50 specimens) were taken because of the large number of larvae collected.

Numerical analysis

Analysis of the catches from this study were used to characterize the spatial structure of the most dominant species, *P. antarcticum*.

Dispersion

First, we have used an index of dispersion (ID) which takes the ratio of the variance to the average abundance of the species for the station grid. If ID equals 1 the distribution is considered random, if it is greater than 1 it is clumped and if ID is lower than 1 it is a uniform distribution.

Spatial patterns

To determine the nature of the spatial structure, and whether it is isotropic or not, a basic geostatistic method was used: the univariate semi-variogram (Matheron, 1962). We computed a semi-variogram from the log transformed abundances. A semi-variogram, often called variogram, is a structural function allowing the study of spatially autocorrelated phenomenon as a function of distance (Legendre and Fortin, 1989). This descriptive method allows a spatial structure to be described from the station grid samples and provides information on the influence of the station grid itself on the interpretation. A variogram is the plot of the semi-variance (g) of the studied parameter calculated between pairs of stations belonging to distance classes (d). This method has been developed for geological research but can also be used in ecology. One of its applications is to map contours of abundance using kriging. For the analysis, we used the abundances from each of the bongo nets instead of summing them as it is often done. In this way, we have two estimates of the abundance for each station which reduces the variance at fine-scale. This may also avoid the so-called 'nugget effect' seen for variograms that do not go through the origin of the graph but showing a non-null variance at distance equal zero. This effect is often observed with biological data because of the sampling variance or because the station grid is insufficient to describe the spatial structure. Primarily, the variogram is calculated for all directions but it is better to compute it by taking different directions to detect whether the spatial pattern is isotropic (same structure whatever direction) or not.

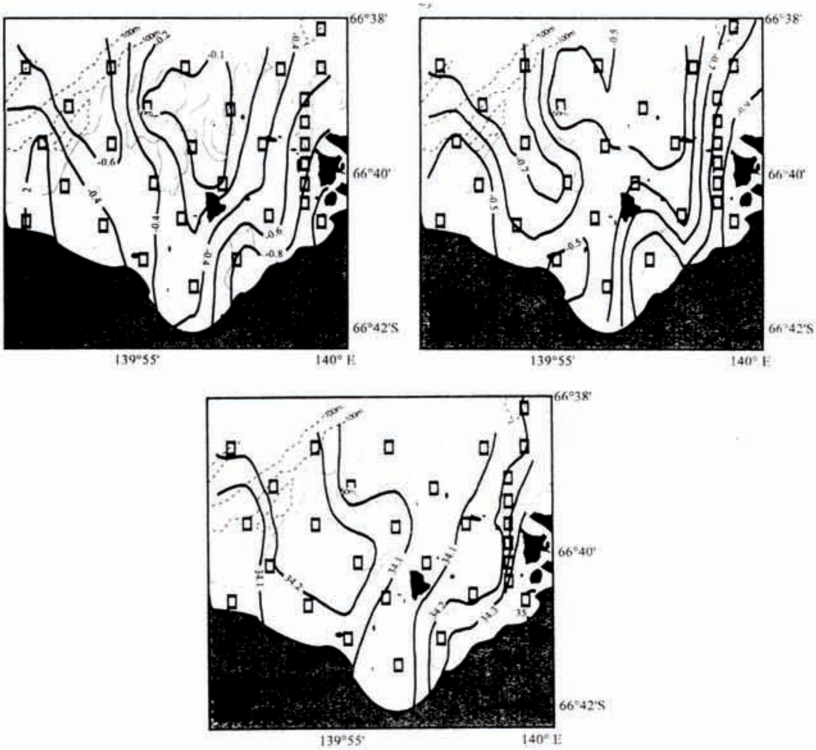


Fig. 2. - a) Surface and b) bottom temperature, and c) surface salinity diagrams derived from CTD profiles in January-February 1996.

Determining the influence of abiotic factors

To determine the role of the abiotic factors on larval spatial distribution, we have used a stepwise multiple regression analysis on log-transformed abundances taking into account different abiotic factors such as: latitude, longitude, depth, bottom and surface temperature, salinity and density. The analysis classifies the factors that significantly explained abundances distribution.

RESULTS

Abiotic factors

The only known results on hydrology for the coastal zone in this locality are derived from observations made by Hureau (1962, 1970) who measured temperature, salinity, dissolved oxygen and pH at two stations at the Pointe Géologie Archipelago that were relatively close to the Astrolabe glacier. No data was available concerning the Pierre Lejay Bay. Temperature and salinity diagrams (Fig. 2) show a longitudinal gradient with the lowest temperatures (-0.9°C) and highest salinities (34.3 p.s.u.) in the south-eastern part of the Bay. The highest temperatures (greater than -0.5°C for the bottom and -0.1°C for the surface) were observed in the mid-northern part and western part of the Bay. Salini-

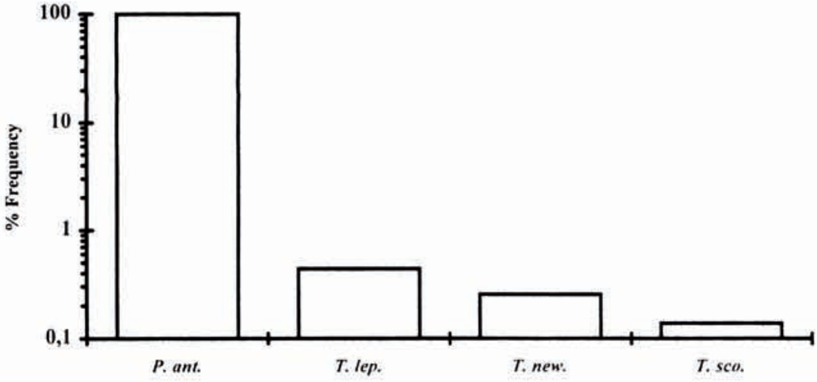


Fig. 3. - Rank-frequency diagram of the Nototheniidae fish larvae collected in whole the Pierre Lejay Bay in January-February 1996.

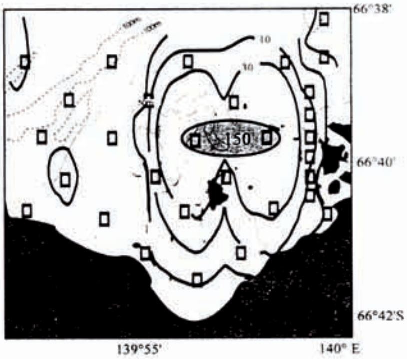


Fig. 4. - Abundance contours (individuals.10m^{-3}) of *Pleuragramma antarcticum* larvae.

ties are relatively low (between 34 to 34.3 p.s.u.) as was observed by Hureau (1962, 1970). If most of the water mass is vertically homogeneous, vertical thermic stratification can be observed at some locations.

Fish larvae

During this survey, 3595 larvae were caught belonging to five species (Table I).

Pleuragramma. antarcticum

P. antarcticum was the dominant species with more than 99% of the abundances as shown in figure 3. These larvae were distributed on the eastern part of the Bay near the numerous islands and islets west of the Pointe Géologie Archipelago, mainly over shallow depths (less than 100 m) (Fig. 4). An average maximum abundance of 17 indivi duals.m^{-3} was observed at two sites. The index of dispersion shows a clumped distribution over the area (ID = 9.08). The all directional variogram (Fig. 5a) shows that there is no spatial structure between each net as the variance is close to 0. A first peak of variance was observed at 0.6 nautical miles which corresponds to the comparisons among stations from the transect along the Pointe Géologie Archipelago (low abundances) and between them and stations showing the highest abundances. A second peak was observed at about

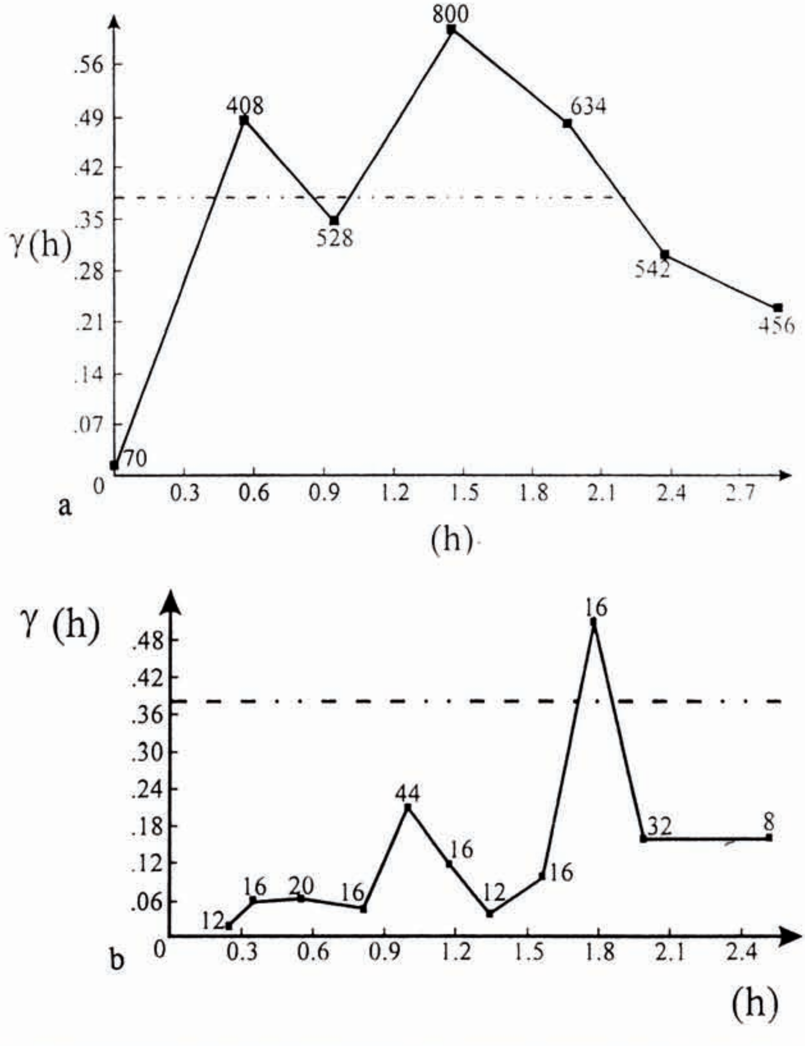
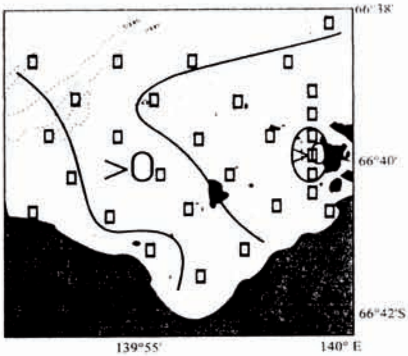


Fig. 5. - a) All directional. b) Latitudinal variograms on log-transformed abundances of *Pleuragramma antarcticum* larvae calculated using both nets of the bongo.

1.5 miles indicating the spatial extension of the swarm. We have studied directional variograms to detect any anisotropy of the spatial structure. Along the longitudes of the

Table I. - Statistical characteristics of standard length (mm).

Species	Number	Mean	Standard deviation	Minimum	Maximum
P. antarcticum	479	17.26	1.75	13.85	22.30
T. newnesi	19	23.55	1.85	20.18	26.65
T. scotti	6	12.46	1.08	10.35	13.39
T. lepidorhinus	7	18.26	2.00	14.70	21.11



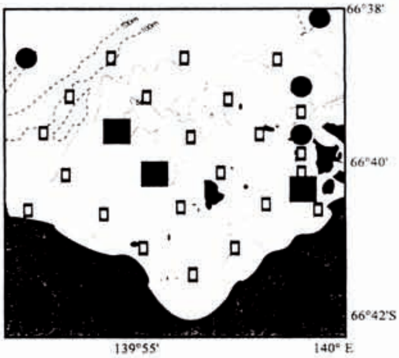


Fig. 6. - Presence of *Trematomus newnesi* larvae in January-February 1996.

Fig. 7. - Presence of *Trematomus lepidorhinus* (circles) and *Trematomus scotti* (squares) in January-February 1996.

sample grid, the analyses showed the same kind of pattern as with the omnidirectional variogram. The latitudinal variogram showed a quite different plot (Fig. 5b). Two peaks are observed which were both linked to the distance between stations within a transect. It showed the sampling effect: the first maximum of variance at about 1 mile was linked to the distance between two neighbouring stations. It is less important than the maximum shown at about 1.8 miles which is the distance of two stations separated by another one on a transect.

Beside abundances, we wanted to know if there was any spatial heterogeneity of specimen standard length. The average standard length is 17.26 +/- 1.58 mm (at a confidence interval of 95%) (Table I). The length frequency distribution is unimodal and there was no evidence of a spatial heterogeneity. Most larvae were at the postflexion stage, some of them showed development of fin rays and a small number were at the transition stage with all rays formed.

Trematomus newnesi

The second dominant species was *Trematomus newnesi*. The 19 larvae caught were at the transition stage with an average length of 23.55 +/- 0.89 mm (at the confidence interval of 95%) (Table I). They occurred in the south-western part of the Bay, close to the Pointe Géologie Archipelago (Fig. 6).

Trematomus scotti and Trematomus lepidorhinus

Trematomus scotti and *Trematomus lepidorhinus* were located at few stations (Fig. 7). The six larvae collected of *T. scotti* were at the preflexion stage (Table I). The

Table II. - Results of the multiple regression of the log-transformed abundance values (individuals.10 m^{-3}) of *Pleuragramma antarcticum* larvae with abiotic factors (hydrology and geography).

Parameter	Estimate	St. error	T. statistic	P. value
Constant	- 2004.27	650.84	- 3.08	0.0047
Longitudes	14.36	4.65	3.08	0.0047
Bottom temperatures	5.64	1.20	4.69	0.0001

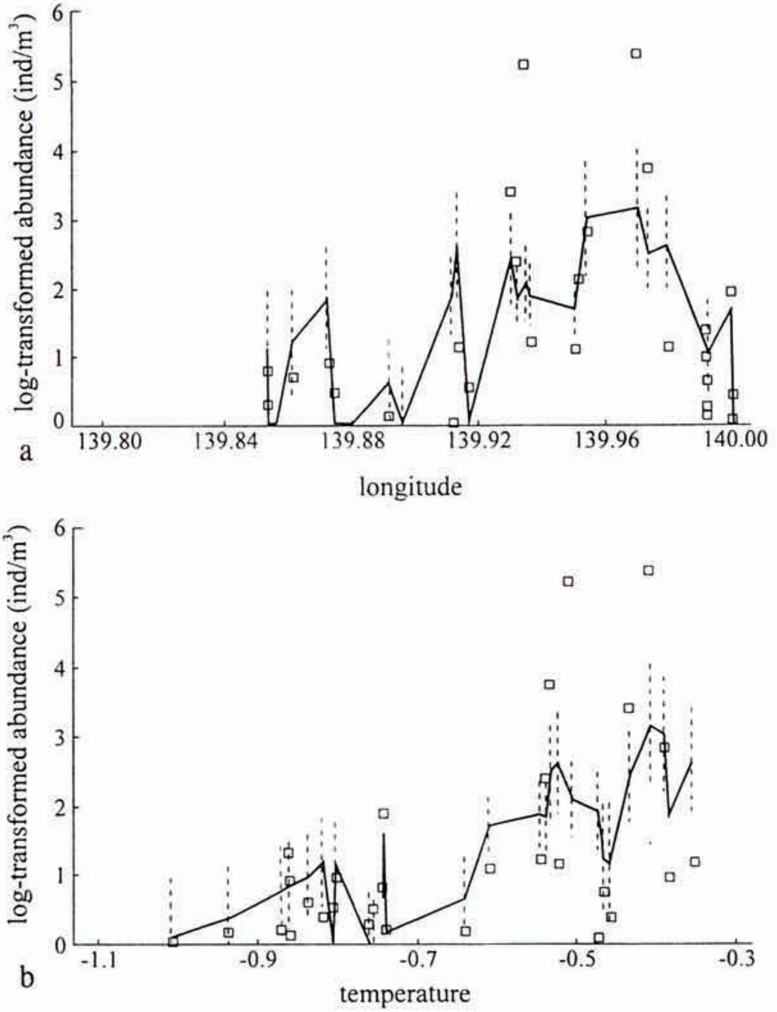


Fig. 8. - Plot of the log-transformed abundance (individuals.10m^{-3}) with predicted values of a) longitude and b) temperature derived from the multiple regression analysis.

seven larvae of *T. lepidorhinus* were at the postflexion stage (Table I). Finally, one larva of *Racovitzia glacialis* of 19 mm was caught at station 62 in February.

As the larval distribution is mainly explained by *P. antarcticum* larvae, we tried to understand the underlying cause for such a distribution. From the stepwise multiple regression (Table II), the influence of abiotic factors are shown (analysis of variance with $p = 0.0002$) with main action of longitudes ($p = 0.0047$) and bottom temperatures ($p = 0.0001$). This confirms the results obtained for longitudes by variograms. From the plot of log transformed abundance with predicted values of longitudes or bottom temperatures (Fig. 8), we see that larvae are localized to the east of the canyon where we find the highest bottom temperatures (> -0.4°C).

DISCUSSION

The Antarctic silverfish, *P. antarcticum,* is unusual among Antarctic notothenioids because it is pelagic during all phases of its life-history. Larvae of *P. antarcticum* were the most abundant in the area with a dominance of over 99%. This value is in accord with other observations made in high Antarctic zones such as the Weddell Sea (Hubold, 1984, 1985, 1990; Hubold and Ekau, 1987; White and Piatkowski, 1993). Dominance values for larval *P. antarcticum* are lower along the Antarctic Peninsula (Kellermann, 1989; Kellermann and Kock, 1988). We can assume that the ichthyoplankton of the Adélie Coast sector is more similar to the high Antarctic zone, such as the Weddell Sea, than in the Antarctic Peninsula (Loeb *et al.*, 1993). Moreover, as noticed by Hubold (1985), abundances are high in a one-species dominant ecosystem such as upwellings with a "low competition niche". Examples of this are the pelagic larvae of pelagic fish such as clupeids in temperate and tropical seas or myctophids such as *Krefftichthys anderssoni* in the Southern Ocean around subantarctic islands (Koubbi *et al.*, 1991; Koubbi, 1993).

Size-dependent vertical distribution of *P. antarcticum* was observed in the Antarctic Peninsula (Kellermann, 1986) and the Weddell Sea (Hubold, 1984; Hubold and Ekau, 1987: Piatkowski *et al.*, 1990). Most larvae and postlarvae were collected on coastal zones at depths less than 100 m. Elsewhere, they are described as being at a depth of 50-100 m (Hubold, 1984; White and Piatkowski, 1993). During our survey, no juvenile specimens were caught as they are supposed to inhabit the shelf between 50 and 400 m in the water column and the adults usually occur below 400 m (Hubold, 1992). This vertical ontogenic stratification is assumed to avoid intraspecific competition by Hubold and Ekau (1987) and Hureau *et al.* (1990). The larvae we found were the young-of-the-year (standard length of 17.26 mm) and hatching will have taken place in November or December if it is similar to that reported for other areas in Antarctica (Kellermann, 1987; Hubold, 1984, 1985). This early occurrence of larvae is thought to be synchronized with peak plankton productivity (Hubold and Ekau, 1990). In autumn, Hureau (1970) described some individuals of *P. antarcticum* that were caught in March in the same area with a standard length of 25 mm (they were originally misidentified as being *Trematomus bernacchii)*; these were confirmed to be young-of-the-year by otolith examination.

Variograms showed that *P. antarcticum* distribution is spatially autocorrelated. The spatial structure is isotropic which is mainly explained by longitudes. It also shows that the swarm has a size of about 1.8 nautical miles by 1.5 n.miles. Finally, this technique gives relevant information concerning the sampling grid. If there are no differences for the stations along the Petrel Island transect, a few more stations are needed latitudinally to describe the swarm more accurately. The spatial distribution of *P. antarcticum* larvae seems to be linked to coastal circulation as shown by longitudinal effects. They are associated with the highest temperatures in the area and are related statistically to high bottom temperatures. Elsewhere in Antarctica, larvae have been found to be associated with higher temperatures (Hubold, 1984; White and Piatkowski, 1993) and it has been suggested that the warmer waters are selected because these provide more favorable conditions for growth and nutrition. Juveniles may be found in more colder waters (Hubold, 1984). Even though we were not able to make direct measurements of local currents, the area is subject to the influence of a major current running westward. We assumed that this current is influenced by the eastern cliffs of the Astrolabe glacier, numerous icebergs and the islands of the Pointe Géologie Archipelago: and this may create small gyres in the eastern part of the Pierre Lejay Bay. These gyres would be favorable to the formation of the distribution pattern observed and the maintenance of the *P. antarcticum* swarm. The exact size of the swarm is difficult to describe precisely because stations of highest abundances were sampled at one day intervals. Further surveys will have to be undertaken to describe this feature and to measure its duration. During the summer period, local gyres will be favorable to plankton productivity and larval retention. In accord with Hubold (1984), we can assume that katabatic wind may destroy such hydrodynamic features and advect postlarvae away from the coastal zone to the shelf. Moreover, this hydrodynamic configuration will help to localize potential spawning grounds, may be in the inner-shelf depression (over 1000 m deep) under the Astrolabe glacier.

It was not possible to detect potential interactions between *P. antarcticum* and the other larval fish because the other species were represented by too few specimens. *T. newnesi* larvae had nearly completed the pelagic phase of their life-history. This species probably spawned in upper sublittoral waters in spring (Kellermann, 1989). Hatching is likely to have occurred in September/October as shown by Kellermann and Kock (1988) and Radtke *et al.* (1988). *T. scotti* larvae were at the preflexion stage. Data on this species indicate that hatching occurs in summer (January-February) (Kellermann, 1990). Elsewhere on the continental shelf, *T. scotti* larval development extends throughout most of the winter and the metamorphosis occurs at a size of 27 mm. Larvae of *T. scotti* are less abundant but occur frequently in Antarctic coastal waters in summer (Kellermann, 1989; Kellermann and Schadwinkel, 1991). Loeb (1991) has found these larvae abundant in the upper 100 m. The larvae of *T. lepidorhinus* were at the postflexion stage. The size was rather similar to individuals caught by Hubold (1990) in the Weddell sea during the same month. They were quite well developed and near metamorphosis, and so we can assume that hatching had occurred in mid-November when we compare these observations with the results of Kellermann (1989) from the southern Bransfield Strait. They are more common over continental shelves as shown by White and Piatkowski (1993), which is also the case of *Racovitzia glacialis.* This is the first record of *R. glacialis* from Adélie Coast. From our results, the distribution of *P. antarcticum* larvae seems to exclude other species thereby avoiding interspecific competition. This competition may be reduced by a temporal succession of the hatching period among the local fish fauna as has been noticed in other areas of the Antarctic shelf (Kellermann, 1989; Hubold, 1990; Loeb *et al.*, 1993) and at South Georgia (North and White 1985). *T. newnesi* and *T. lepidorhinus* are near the end of their pelagic phase in January with mainly transition larvae and *T. scotti* having relatively young larvae.

As Hubold (1984) stated, larvae of *P. antarcticum* successfully occupies the pelagic niche avoiding intraspecific competition by spatial segregation of life-history stages and interspecific competition by temporal succession between species. This species is likely to be a good indicator of the long term-changes in the pelagic system of the high Antarctic zone as was already mentioned by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). The next objective will be to study the larval nutrition as a function of plankton abundance and diversity and to organize a temporal survey to describe parameters such as growth, condition and mortality in the coastal zone of Adélie Land.

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